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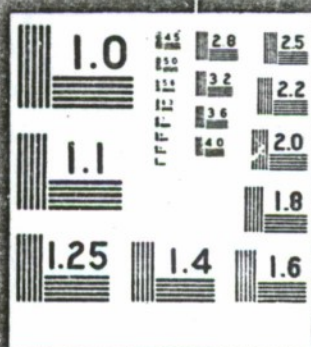
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13. ABSTRACT

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The MIRA Bulletin No. 5, 1969, contained an article in which the Sierra anthropometric dummy was discussed. Mr. Hertzberg, who is collaborating with American manufacturers on the development of dummies, has now submitted some comments which he has asked us to include in the Bulletin. A reply by the authors of the original article follows Mr. Hertzberg's comments.

Misconceptions Regarding the Design and use of Anthropomorphic Dummies

by H. T. E. Hertzberg

Aerospace Medical Research Laboratory, United States Air Force

Mr. Hertzberg, a research physical anthropologist, has been practicing engineering anthropology for the U.S. Air Force since 1946, measuring human body size and strength, and utilizing such data in the design of dummies, cockpits, seats, oxygen masks, helmets, gloves and other types of flying clothing and personal equipment. He received an A.B. from Rice Institute in 1927, and an A.M. from Harvard in 1942. Between those years he graduated from the U.S. Military Flying School at Kelly Field, Texas, worked in engineering and aerial mapping, did graduate work at the University of Texas and at Harvard, and field and laboratory research at Harvard and the Universities of Texas and Kentucky. He joined the Aerospace Medical Research Laboratory after military service in World War II.

Mr. Hertzberg is author or co-author of about 60 monographs and papers, as well as of numerous anthropological chapters in official Air Force publications. He is a member of several national advisory committees, including the Committee on Physical Anthropology, National Research Council; and for five years was Chairman of the Committee on Anthropometry, Aerospace Medical Panel, AGARD-NATO.

UNDER the very general title, "Anthropometric* Dummies for Crash Research", Searle and Haslegrave (1969) launch a series of sharp criticisms against a commercial crash-test dummy, Model No. 292–800 built by Sierra Engineering Company, Sierra Madre, California. The authors inveigh against what they call "misconceptions" on Sierra's part. For reasons presented below, I consider it unfair that Sierra should bear the brunt of the attack, and therefore undertake an analysis of some of the criticisms. My remarks here are my personal views, and are not necessarily those of my employer.

Furthermore, my comments here should not be construed as an apologia for Sierra. That company must take responsibility for its own design decisions. But if Sierra utilizes design parameters (like size, shape, weight distribution) that are recommended by committees of American experts on human-factors design practice, then Sierra is not the real culprit. Indeed, for some of what Searle and

Haslegrave call Sierra's mistakes, I should be called to the dock instead, having had some part in establishing those parameters and the underlying design philosophy. It is for this reason that I reply here, hoping that a little understanding may put these complaints in their true light, and thereby dispel some of the confusion.

But because dummy-making is an esoteric activity which most people have never heard of, some background may be called for. A reasonably full outline of anthropomorphic dummy development can be found elsewhere (Hertzberg, 1969), but for immediate purposes of my identification with the subject, the following may suffice:

(a) in 1949 I assembled comprehensive specifications for the size, form, mobility and weight distribution for the first "anthropomorphic" dummy (built by Sierra Engineering Company in that year), from which both existing commercial dummies (Sierra, Alderson) have grown.

(b) I am a member of two national committees (SAE; Department of Transportation), each involved in a different aspect of the design and construction of automotive crash-test dummies. Both committees include government research anthropologists and automotive engineers, and the second also has representatives of both dummy manufacturers. Technical descriptions of

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*The term, "anthropomorphic" has been used for 20 years in the United States to denote a dummy deliberately engineered to simulate a specific level of human size and structure—the type we are discussing here. In the beginning it was called the "anthropometric dummy" because its specifications had emanated from what was then called "Anthropometric Unit".

the latest dummy specifications chosen for Department of Transportation crash-test dummies have been published (Starkey, et al., 1969).

Dissatisfied with their Laboratory's home-made test dummy, Searle and Haslegrave bought the commercial Sierra dummy. In the first section of their paper, Choice of Dummy Dimensions (p. 25), the authors lose no time in stating their complaints: " . . . it became apparent that the makers are wrong in their understanding of what constitutes a 95th-percentile man, i.e., a man of such size that 95 per cent of the population are smaller." The authors then assert that, to define a 95th-percentile man, ". . . only one dimension can be chosen." On the same page they say further: "The attempt to use a number of dimensions jointly is not only meaningless . . ., but in addition gives rise to a number of self-contradictory results. This is illustrated by an example from reference (2) [i.e., Hertzberg et al., 1954]. Seated shoulder height may be thought of as the sum of elbow height and length of upper arm. The 95th-percentile value of seated shoulder height [Shoulder Height, Sitting for those who wish to check the original reference—HTEH] is 25·1" while the two portions have 95 percentile values of 10·8" and 15·4" respectively, with a sum of 28·2" (sic)."

Now here is a curious intermixture of truth and error, and to separate the two requires a fairly detailed analysis. But before doing this, let me quote yet the next paragraph in full, to do no violence to context:

"The designers of the Sierra dummy appear to have attempted to make the dummy 95th percentile on a large number of dimensions, and the internal contradictions resulting from this misconception have given rise to some odd proportions for the dummy. In particular the neck is far too long, and the height of the iliac crest when seated is too low. In addition, all body widths and circumferences, including thigh, hip and chest circumferences, are too large. The specified weight of the dummy (217 lb.) is also too large—the mean weight of men of 73·1" stature is 188 lbs. (1) [i.e., Stoudt et al., 1965]. It appears that the makers have taken major dimensions such as weight, stature and limb dimensions, from Ref. (1), and filled in with detailed dimensions from Ref. (2). The discrepancies, introduced by the attempt to reconcile incompatible 95th percentile values, have a great effect on dummy kinematics, which will be discussed later."

We have now before us the gist of the first area I wish to discuss. How to begin is a bit of a problem, but perhaps the simplest way is to begin with the simplest error.

For the sake of precision, it is necessary to note the error of addition above: the sum of elbow rest height and shoulder-elbow length is 26·2", not 28·2" as in the text.* In all fairness, this can be dismissed as a mere typographical error. The true difference (1·1") between shoulder height and the sum of those two dimensions may loom large in an engineer's mind—and the authors are correct that for an individual person the two sets of dimensions should be equal—but to an engineering anthropologist it seems quite small, because dimensions for a statistical sample do not behave the same as for an individual. The biological fact, well known to anthropologists, is that body proportions differ markedly among both individuals and racial types (Hertzberg, 1968). Some people have long torsoes with

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*Mr. Hertzberg was notified of this misprint during the preparation of his article.—EDITOR.

short arms and legs, while the reverse is true for others. Hence elbow-rest height cannot be the same for these different types, and this is why elbow-rest height has to be directly measured and directly applied. In no random sample of sitting people that I know of will the value of shoulder height equal the sum of these two dimensions. So marked is this variability that, while the Coefficient of Variability (a percentage expression of the standard deviation) is around 4·4 for most anthropometric dimensions, that for elbow-rest height is 11·36 (Hertzberg, Daniels and Churchill, 1954, p. 22). Roughly the same values are true for totally different samples (Hertzberg et al., 1963, p. 142). Thus this example, expected by the authors to bolster their case, shows instead that their acquaintance with anthropological human-factors principles is not complete. Sierra cannot be blamed for that.

Now, what of the authors' statement that only one dimension can be used to designate a given percentile level for a man—say, the 95th? Here they are perfectly correct—for a man. The term, "the 95th-percentile man" is only a statistical abstraction—when used to describe a man. There is no such thing as a man who is 95th-percentile in all dimensions. Anthropometric data show that, of those men who are of the 95th-percentile in stature, only a few may also be of that level in weight; and as the number of dimensions increases the number of men actually displaying that level in other dimensions drops very rapidly to the vanishing point. The same is true for that other popular but non-existent abstraction, the "average man" (Daniels, 1952). But while all this is true of a man, it is not true of the anthropomorphic dummy. One should not expect the same sizes, or the totality of response, in such a dummy as are observed in an individual man.

The point throughout is that the dummy is a tool—a simulator—whose function is to represent not just one man but a whole population of men in as many parameters as possible. It is 95th-percentile in every category, and its response is a blanket response. In crash-test work, a prime requirement is to check out the size and strength of the equipment—the seat, the restraint harness—to make sure it will safely restrain a human subject in the final tests at high G-forces. Even the restraint harness has to be large enough for the 95th-percentile of any dimension. Among a group of 95th-percentile men in stature, weight may vary from about 135 pounds to 240 pounds or more. The load distribution on a seat can therefore vary widely. At 20G, will a seat engineered for 188 pounds (the authors' desired "average") safely hold a man who weighs 240 pounds, or even only 217? Engineering to the "average", apparently espoused by the authors, is a widely-used idea, but it can be shown to be a fallacy nonetheless (Hertzberg, 1955; 1960). Human factors specialists in the United States have long accepted the view that designing to the range of accommodation is the only safe procedure; hence a dummy that will test equipment to its maximum in all parameters is essential. Thus the use of many parameters is not "meaningless"; it is in fact the efficient way to assure maximum utility and safety.

The committees mentioned recommended 217 pounds as the correct level of weight because that is the 95th-percentile value appearing in the latest survey of the American civilian population (Stoudt et al., 1965; the authors' reference 1). Sierra reasonably followed those recommendations; so whoever is "wrong" on this point, again it is obviously not Sierra.

In place of the 217 pounds, the authors call for a value of 188 pounds, which they positively assert, with a reference to prove it, is "...the mean weight of men of 73·4" stature." This statement raises the anthropologists' eyebrows again, perhaps on several counts. First, the reference is incorrect; there is no such statement or value in that report, nor is there a table of average weights for a given stature; and the same is true of the other American report cited. Then where did the authors' choice come from? I do not know for certain. Possibly it came from a sample of British pilots measured in 1955 by Morant, and reported on by Samuel and Smith (1965). In Part II of that report, R.A.F. pilots 73·4" tall are stated to average 187·4 pounds in weight. The similarity of the data make this source possible. But not knowing positively, I refrain from pointing out the impropriety of demanding the use of an average describing a very specially-selected military group in one population as the correct value for a dummy deliberately intended to represent a specific percentile level of a general civilian group in a totally different population. If that guess actually were correct, and one were having to judge the case, the felicity of dummy selection from the several types available would surely be a factor.

So much for the "misconceptions" the authors ascribe to Sierra in their first section, Dummy Dimensions. Let us turn to their next section, Weight Distribution. The authors say, "Two other important factors in body kinematics are the distribution of total body weight among the various body segments, and the centres of gravity of these segments. The published data in this area is very sparse and unreliable." All this is true. Then, however, they cite Fischer (1906; their reference 7) and imply that the centre-of-gravity data for the dummy were taken from that source—noting that it was "a man 4 feet 11½ inches tall and weighing 6 stones 13 pounds" (97 pounds). That implication is unwarranted. In neither the original nor present-day compilations did I use the Fischer data; instead I used the data from three German cadavers studied by Braune and Fischer (1889). From my own independent but unpublished checks of those data I have come to have considerable confidence in them as a point of departure for dummy construction. Bernstein's data ought to be valuable, but so far as I know are not obtainable in the United States in the original document. Up to now, the committee has relied primarily on Braune and Fischer and on Dempster (who did his work—Dempster, 1955; authors' reference 6—at my request). Again, any disparity in weight distribution between the Sierra dummy and Bernstein's data—which the authors appear to favour as the best—cannot be held against Sierra; until Bernstein's work is available in the U.S. for study, the committees are unlikely to specify it. New data will be used as they appear.

Having frequently disagreed with the authors in their previous sections, I largely agree in the next section, Structural Design (on the basis of the photographs), with their contention that the Sierra dummy pelvic and shoulder structure may not properly simulate human skeletal configuration. Perhaps the authors, in selecting the model to purchase, should have compared structure in both makes more carefully. It is, however, a very difficult matter to simulate the human body, as the originators of the RAE Mark Vb doubtless would testify; so difficult, in fact, that the authors set that one aside and purchased a dummy they thought would be better. Perhaps they should not complain too bitterly if the new one is not perfect either. All

dummies are only approximations to the human body; it depends on the purpose of the dummy as to how it is built. The perfect dummy for all purposes is still far in the future, but an SAE sub-committee has been working on standardising the size and shape of a dummy pelvis, which may well be adopted by both manufacturers.

It is easier to criticise than to build. May I urge Searle and Haslegrave to assemble specifications for their own populations? If they would then either construct their own dummy or persuade established manufacturers to build a new model to English specifications, perhaps on guarantee of a certain number to be sold, much of the previously expressed dissatisfaction might be allayed. For the overriding principle inexorably holds: just as anthropologists know that anthropometric data for one national population cannot adequately represent a quite different population, so a dummy designed to represent one group will not be fully satisfactory for another. We can only hope that all governments everywhere, recognising the need for safety of their people in vehicles, will subsidise energetic and dedicated young researchers like Searle and Haslegrave to create test dummies to represent their own populations. All dummy construction will be improved thereby.

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Reply by the authors of the original article, J. A. Searle and C. M. Haslegrave

MR. HERTZBERG does not appear to follow the main gist of our discussion on dummy dimensions. We do not disagree with the measured values of 95th percentile dimensions for the U.S. population, but it is not possible to build a dummy incorporating all 95th percentile values. This is because the sum of two 95th percentile values is not the same as the 95th percentile of the sum; this equivalence is in fact valid only for the 50th percentile. Therefore if lower leg and upper leg lengths are both given 95th percentile values, the whole leg length will not be 95th percentile but will be rather larger.

This difference between the sum of the 95th percentile values and the 95th percentile of the sum, which was 1·1″ in our original example, is much too large for Mr. Hertzberg to claim that it is due to differences between individuals. In fact the complete data (1) from which this example was taken shows that the difference of 1·1″ fits in with a consistent trend:—

TABLE 1
Comparison of sum of percentile values with percentile of sum

	99th	95th	50th	5th	1st
Elbow height, sitting	11·5	10·8	9·1	7·4	6·6
Length of upper arm	15·9	15·4	14·3	13·2	12·8
Sum of components	27·4	26·2	23·4	20·6	19·4
Shoulder height, sitting	25·8	25·1	23·3	21·3	20·6
Difference	1·6	1·1	0·1	−0·7	−1·2

(All dimensions are in inches)

The same trend may also be demonstrated in Mr. Hertzberg's data from Turkey, Greece and Italy (2).

It may be shown that if the component dimensions have normal distributions, to which many human dimensions approximate, and have standard deviations σ_x and σ_y, then for the 95th percentile this difference is given by

$$1·64(\sigma_x+\sigma_y-\sqrt{\sigma_x^2+\sigma_y^2+2\rho\sigma_x\sigma_y})$$ where ρ is the correlation coefficient between the component dimensions. The con-

stant of 1·64 arises from the fact that the 95th percentile is 1·64 standard deviations above the mean; for the 99th percentile it is 2·33 and for the 50th percentile it is, of course, zero. A treatment of this subject may be found in text books on statistics (3). Mr. Hertzberg's claim to be able to add percentile values is valid only for the 50th percentile values since the other possibility, perfect correlation of $\rho=1$ between body dimensions, is demonstrably not the case (4).

The incorrectness of adding percentile values is the direct cause of the odd proportions of the Sierra dummy. If each segment—lower leg, upper leg, torso length, shoulder to top of head—is given its 95th percentile value, then the total will be 3 or 4 inches greater than 95th percentile stature. This means that either the dummy comes out much too tall, or else 3 or 4 inches have to be arbitrarily lopped off one segment. Sierra have chosen this second alternative, probably accidentally through determining torso length by subtraction of the other components from the total stature. The effect is to make the torso considerably too short, and this makes the proportions of the Sierra dummy noticeably odd even to the unaided eye. This is illustrated in the accompanying photographs, Fig. 1.

In order to get a true "range of accommodation", and to be able to determine what percentage of the population is accommodated by the equipment under test, it is necessary to decide which human dimension is of greatest importance for the problem in hand. A dummy is then constructed having the required percentile (say 95th) of this primary dimension, and other dimensions typical of those members of the population who have that value of the primary dimension. In Mr. Hertzberg's example, seat strength, the obvious choice of primary dimension is weight, and a dummy should be used having a 95th percentile weight of 217 lb. (5). Other dimensions such as stature should be given the mean value for people of weight 217 lb., i.e., the stature should be 70·0″ (6). For other problems, such as the correct fit of seat belts, stature would be a better choice for primary dimension, and one would have a 95th percentile stature of 73·1″ (5) and a weight (188 lb.) typical of men of this stature. Mr. Hertzberg seems to suppose that men of 73·1″ stature average 217 lb. weight, and that men of weight

217 lb, average 7.91" stature, but in fact neither of these suppositions is true. Although ideally a different dummy is required for every problem, most problems of common occurrence are either stature related or weight related, and unless special conditions apply these two types of dummy are sufficient. This will be further discussed in an article in the next Bulletin, which describes the practical aspects of designing a dummy.

Incidentally, we are grateful to Mr. Hertzberg for noticing that the figure of 188 lbs. quoted above is not to be found in the reference given in our article (5). It is in fact in a supplementary paper (6) which was issued later by the same organisation.

Perhaps it is worthwhile to clear up some other minor points raised by Mr. Hertzberg:
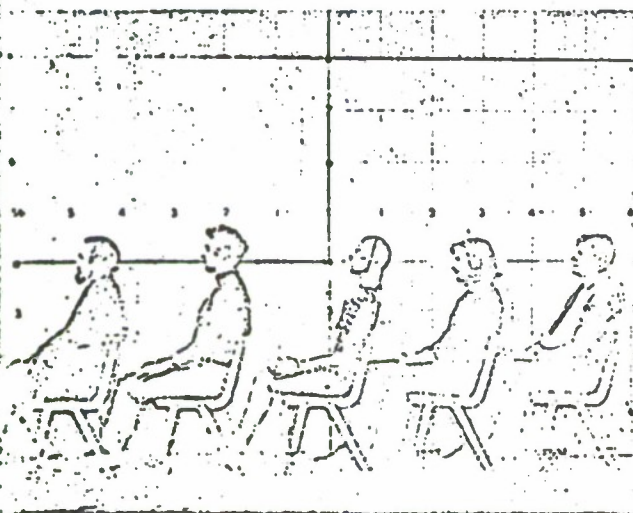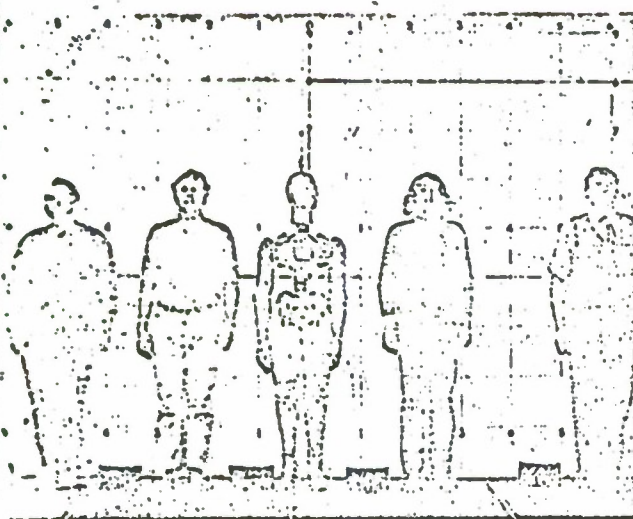

Figure 1. Comparison of the proportions of the Sierra dummy with some subjects of similar size.

(1) The term "anthropometric dummy" is in current use by such people as Sierra (7) and Mr. Hertzberg himself (8). It refers specifically to our present main concern, the dimensional properties of the dummy.

(2) We said that data on weight distribution is very sparse, and mentioned Fischer in 1906 and Bernstein in 1931 to illustrate this. Mr. Hertzberg now tells us that he uses the still older data of Braune and Fischer in 1889. Reference to our original article will show that there was no implication that Sierra had used any particular set of figures for weight distribution and in fact we went on to say that "the Sierra dummy is in broad agreement with what data there is, . . .".

(3) We agree that the strength and mechanical construction of a dummy will depend upon the use for which it is intended. However, the Sierra dummies in the 800 series are "specifically designed to meet the rigid requirements of automotive industry testing" (7) and it is for just this use that they have unsatisfactory mechanical features.

(4) Finally, we are not concerned with British data, but with the design of an American dummy to test cars to American market requirements. Mr. Hertzberg's suggestion of differences in racial types is completely irrelevant in the present context.

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